CHAPTER 8
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 SUMMARY

This thesis aimed to investigate the mechanisms behind valley closure and upsidence over unmined coal and old longwall panels using UDEC. In order to achieve this, the choice of UDEC had to be justified and verified with the New South Wales Department of Primary Industries empirical method of subsidence prediction (Holla & Barclay 2000), the empirical method developed by Waddington Kay and Associates (2002) for valley closure and upsidence, and two analytical solutions.

One alternative explanation for valley closure and upsidence above unmined coal was proposed and successfully investigated with UDEC.

This research has been driven by the need for understanding why valley closure and upsidence occur above unmined coal, a phenomenon which can have far reaching consequences in terms of surface damage and the possibility of forced sterilisation of coal.

This project is a successful demonstration of the principles of using numerical, empirical and analytical techniques to investigate a complex problem.

8.1.1 Review of problem

A review of valley closure and upsidence was undertaken and it was found that very little literature exists on this topic. The most comprehensive review to date had been performed by Waddington Kay & Associates (2002) and in this reference, a conceptual model was proposed that suggested valley closure and upsidence is a result of some undefined horizontal compressive stresses. It was speculated that this conceptual model may be valid for river valleys that are directly undermined by longwall panels. The suggestion by Waddington Kay and Associates that upsidence is directly related to valley closure was challenged.

The field data in Waddington Kay and Associates (2002) illustrated that valley closure and upsidence was occurring above both unmined coal and old longwall panels (Figure 3.8 and Figure 3.12), thereby raising questions about the wide application of this horizontal compressive stress model, especially in areas above unmined coal that are theoretically in tension and over old longwall panels which would have been relieved of high horizontal compressive stresses during the extraction process.

Therefore, the questions that were raised about the horizontal compressive stress model were:

1. Why does valley closure and upsidence occur in the tensile or hogging portion of the subsidence profile above unmined coal?
2. Why does valley closure and upsidence occur over old longwall panels?

8.1.2 The block movement model

To address the short-comings of the horizontal compressive stress model detailed in Waddington Kay and Associates (2002) and to provide answers to the questions posed above, an alternative model of block movements was proposed (Chapter 3).

The block movement model proposed that an incised ground surface is comprised of an assemblage of blocks such that the valley incisions can be represented by the absence of blocks. When the ground surface sags due to the extraction of a longwall panel, the horizontal shortening of the ground surface above the longwall panel results in the blocks being forced into the free face provided by the valley (Figure 3.17), whether it be over unmined coal or old longwall panels.

This model assumed that the blocks had a surface to slide along, termed the translation plane. If the translation plane existed at the bottom of the valley, then it was proposed that valley closure would dominate over upsidence due to the dissipation in horizontal stress provided by the translation plane. If the translation plane existed at a distance below the bottom of the valley, then it was proposed that valley closure would be reduced and upsidence increased.

The kinematics of a particle moving along a curved surface was described and it was pointed out that an adaptation to blocks moving along a curved surface was possible but needed further investigation. It was deduced that the kinematics related horizontal movement of the blocks to valley depth and curvature (Equation 3.12).

8.1.3 Numerical modelling

The numerical modelling was undertaken in accordance to the guidelines set out in Hudson, Stephansson and Andersson (2005). This was done to ensure that the modelling process was fully traceable and transparent.

A review of recent references that dealt with UDEC, FLAC and similar software in mining or underground applications was undertaken. It was found that whilst UDEC seemed to be a more logical choice for modelling discontinuous rock masses, there was a trend of using FLAC and creating custom constitutive models and calibrating material properties. This approach is acceptable when a predictive model is required for a localised area, but does not lend itself to a true predictor status. It was decided that UDEC was the most appropriate software to use for this project because it did not require the creation of a custom constitutive model or the excessive calibration of material properties to replicate the effects of jointing.

The single longwall panel numerical models were created so they could be verified with the empirical method. The geometry of the models and the model parameters were derived from the literature. The models were designed to be transparent, and all the model parameters and assumptions were fully traceable. It was also decided to make the models as simple as possible to decrease the number of assumptions that had to be made, as the more complex a numerical model is, the more uncertainty is built in. The models were designed to predict maximum subsidence, goaf edge subsidence, strain, tilt and inflection point location.

When the models were analysed, it was seen that a goaf angle does exist and that the caving was largely contained below the Bulgo Sandstone. This was in good agreement with the factors identified in the literature survey on mine subsidence. When the results were compared to the empirical curves (see Figures 5.8 to 5.13), it was seen that the numerical predictions were in good agreement with the empirical curves. The only parameter where the numerical predictions showed some limitations was the strain predictions. This was attributed to the small levels of strain predicted and the inability of the numerical model to predict strain of such small magnitude.

After the success of the single longwall panel models, a series of models were created to simulate river valley response to mining in order to test if the proposed block movement theory in Chapter 3 was plausible. Instead of creating a full scale model that encompassed everything between the longwall and the surface, it was decided to scale the model down by replicating the surface profile with a sequence of vertical displacements that were applied to the new base of the model.

The new base of the model was determined by analysing the vertical displacements of the surface, the Bald Hill Claystone and the Bulgo Sandstone. It was found that the vertical displacement of the Bald Hill Claystone differed little from the surface vertical displacements. When the Bald Hill Claystone was used as the base of the model, the chance of yielded elements occurring in the vicinity of the river valley was too great to ignore. As a result of this the Bulgo Sandstone was used as the base of the models, thereby restricting yielded elements to those directly related to valley base yield, and not those that were a by-product of the modelling procedure. All material and joint properties remained the same as in the single longwall panel models to maintain consistency.

Two types of models were developed. The first type incorporated a translation plane at the base of the valleys and the second type incorporated a translation plane located one metre below the base of the valleys. The purpose of this was to test the proposed block movement theory in Chapter 3. It was noted that there was some uncertainty with the exact definition of upsidence, and it was decided that for the purpose of the modelling, upsidence was defined as the difference in upsidence between models with the translation plane at the base of the valleys, and the models with the translation plane below the base of the valleys. Several variations were included in the numerical modelling, including adding bedding and joints in the upper 70 m of the Hawkesbury Sandstone, and adding joints to the beam formed by the translation plane.

The models behaved according to the proposed block movement theory and compared well to the empirical and field observations (see Figures 6.20 to 6.59). The modelling also demonstrated that tilt/curvature was the primary driver of valley closure and upsidence, and was not controlled by a redistribution of horizontal stresses as widely thought. A parametric study was conducted on the translation plane cohesion and friction angle (see Figures 6.60 to 6.63), and it was found that it was possible to quantify a joint cohesion and friction angle that was required to limit movement along the translation plane.

The key objective of the numerical modelling was to demonstrate the block movement model, a goal that has been achieved.

8.1.4 Application of analytical solutions

In an attempt to further the credibility of the numerical models, it was decided to apply the voussoir beam solution to the single longwall panel models and the plate buckling solution to the river valley models to see if the models corresponded with proven analytical solutions. From the results it was seen that the voussoir beam solution back calculated the goaf angle satisfactorily (see Table 7.1) and the plate buckling solution corroborated with field observations (see Figure 7.1 and Figure 7.2). Both types of models agreed well with the analytical solutions, even though the analytical solutions were derived for elastic material.

8.2 CONCLUSIONS

The following conclusions were drawn from this research project:

- UDEC was suitable for use in mine subsidence related problems. This was illustrated by the excellent match to the empirical curves used for validation purposes. As UDEC is a Distinct Element code, the inclusion of joints automatically accounted for the reduction in rock mass strength, therefore eliminating the need to modify or calibrate material properties derived by laboratory testing. This is keeping in accordance with the transparent and fully traceable principle.

- The block movement model was a feasible explanation for valley closure above unmined coal and old longwall panels. The numerical modelling demonstrated that the forces generated were sufficient to induce movement in the hogging portion of the subsidence profile by forcing blocks in an outward direction into the void provided by the valley. In addition, the kinematics was relatively simple and explained the relationship between block movement, valley depth and tilt/curvature.
- The block movement model was capable of indicating the onset of valley base yield. This was extensively demonstrated in the numerical modelling.
- The block movement model also introduced a number of implications. Block rotations on a curved surface may induce surface cracking that extends to the depth of the adjacent block, in any case much deeper than might be expected. The depth of this surface cracking coupled with bedding plane dilation may have adverse effects on horizontal permeability as well. It may be possible to control the magnitude of upsidence or valley closure by reinforcing the valley base in critical situations.
- The block movement model demonstrated that it was possible to predict valley closure and the onset of valley base yield using block kinematics and the plate buckling solution. Further refinement is needed to replace numerical models with analytical solutions; nevertheless the basic principles are sound.

8.3 LIMITATIONS OF THE STUDY

Modelling longwall caving, subsequent subsidence and river valley response is complex and required simplifications and assumptions. The modelling work was limited by the following conditions:

- No three dimensional modelling was undertaken. Given the amount of unknown assumptions that would have had to be made, limiting the modelling to two dimensions was prudent.

- The difficulty in replication pillar deformation restricted the modelling to single panel longwalls.
- Some material properties from the geotechnical characterisation (MacGregor & Conquest 2005) were missing and had to be evaluated using the Mohr-Coulomb failure criteria and various guides.
- Joint properties were not available and had to be assumed.
- Vertical joint spacing was impossible to determine from core samples and was assumed to be the same as bedding plane spacing.
- Reproducing bulking in the goaf was difficult. Again, time constraints prevented additional models being created with more random sub-vertical joint orientations to try and increase bulking.
- No field data was provided in order to verify models, the empirical method was used for verification instead and this in itself was not ideal due to the data scatter evident in the empirical curves.

8.4 RECOMMENDATIONS

This project achieved its objectives and it also highlighted areas that would benefit from future research. These areas are:

- The application of UDEC as a greenfields subsidence prediction tool in sub-critical mining environments. This project has demonstrated that UDEC is capable of predicting subsidence for single isolated panels provided that the material properties are known.
- The establishment of a geotechnical database containing typical rock mass and joint properties for the rock units in the Southern Coalfield. Compiling the data needed for the numerical modelling was one of the most time consuming processes in the entire project.
- It would be advantageous to model a wider range of longwall panel geometries to try and cover the majority of the empirical prediction curve. For this to occur, bulking needs to be replicated in the goaf to correctly model the large increase in subsidence evident when W/H ratios exceed approximately 0.5.
- In order to model multiple longwall panel layouts, further investigation into the mechanics and numerical modelling of pillar deformation should be undertaken.

- Valley closure could theoretically be evaluated using block kinematics. Further research needs to be carried out to derive expressions to calculate the forces exerted by one block to another, and therefore displacement as the blocks undergo rotation due to the development of the subsidence trough.